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THE VERTICAL PHYSICAL APERTURE IN THE MAIN RING

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December 26, 1972

The Survey Data

Survey of the vertical position of the main ring magnets has been conducted during the 2nd and 3rd of October 1972. The survey data have been collected and properly corrected of the errors of the system of detection used (as, for instance, the earth curvature). They are presented in the following final form.[1]

For every magnet, either quadrupole or dipole, the vertical displacement of the two ends are given with respect to the so-called "4-th order reference curve". This is a smooth curve which best fit the position of the quadrupoles of the previous survey made during October 1971, and which is taken as the reference curve on which all the quadrupoles are required to be located. The dipoles then are to be aligned on the straight line through the two neighbour quadrupoles. The choice of this curve as reference for the magnet position implies that only small adjustments need be made for a better vertical realignment of the ring.

Figs. 1 and 2 show the actual vertical displacement of the magnets from the "4-th order reference curve". The station numbers are shown on the bottom. Every small division refers to a magnet: the first to a quadrupole, the other four to the dipoles. Displacements of both ends of the magnet are shown only if larger than ± 50 mils. To give a better idea how to read the figures, an enlarged portion of the diagram by a factor of 5 is shown at the bottom of Fig. 2.

The survey data relative to the two doublets upstream and the two doublets downstream in each of the 50 m long straight sections have not been included in the following analysis. Also, we do not have data for the dipole at F26-3 and we assumed it was properly aligned (zero vertical displacement).

It is worthwhile to mention that the magnets at the following positions have been replaced since the survey was made:

A47-3	B14-3	B18-4
B24-1	B36-4	C18-4
E44-3	F27-2	F37-1

Also, inspection of Figs. 1 and 2 shows an "apparent" sinking of the whole sector B and the beginning of the sector C.

Aperture Calculation

The physical aperture available in the quadrupoles and in the dipoles has been calculated in different ways.

(a) Quadrupoles

Each of the two ends of a quadrupole is described by the following parameters:

ϕ, vertical phase advance

s, longitudinal coordinate along the ring

β, vertical beta-value

y_o, elevation of the magnet geometrical axis from the 4-th order reference curve

y_c, elevation of the closed orbit from the geometrical axis

a, half aperture of the magnet

d, elevation of the closed orbit from the 4-th order reference curve

b_{up} and b_{down}, the aperture available respectively above and below the closed orbit.

With reference to Fig. 3 we have

$$d = y_o + y_c$$

and

$$b_{up} = a - y_c \quad , \quad b_{down} = a + y_c \quad .$$

Similarly, we define

$$\varepsilon_{up} = \frac{b^2_{up}}{\beta} \pi$$

$$\varepsilon_{down} = \frac{b^2_{down}}{\beta} \pi \qquad (1)$$

as the available acceptances respectively above and below the closed orbit.

(b) Dipole

Each end of a dipole is described by the same parameters listed above, and moreover:

y_{up}, elevation of the axis of the upstream quadrupole from the 4-th order reference curve

y_{down}, elevation of the axis of the downstream quadrupole from the 4-th order reference curve

L, distance between two next quadrupoles

ℓ, distance from the upstream quadrupole

p, elevation of the rectified orbit through the centers of the two next quadrupoles from the 4-th order reference curve.

Besides, now, y_c is the elevation of the closed orbit from the rectified orbit through the centers of the two next quadrupoles.

With reference to Figs. 4 and 5 we have

$$p = y_{up} + (y_{down} - y_{up}) \frac{\ell}{L} \quad .$$

$$d = y_c + p$$

and

$$b_{up} = a + y_o - y_c - p \quad , b_{down} = 2a - b_{up} \quad .$$

The acceptances are still defined by Eq. (1).

<u>Processing and Results of the Data</u>

1. <u>Ideal case: no vertical misalignment of the magnets and no vertical closed orbit distortion</u>.

There are only 6 spots where the acceptance of the ring is less than 5 π mm x mrad and these are at the downstream end of the B1 dipoles:

A48-5, B48-5, C48-5, D48-5, E48-5, F48-5 (2)

Calculations of the available acceptance have been carried out assuming a half-aperture of 0.70" for the B1 dipoles and 0.95" for the B2 dipoles. If the horizontal closed orbit goes also right through the axis of the quadrupoles where the half-aperture is of 1.70", the acceptance at the positions (2) above (and, hence, the acceptance of the ring) is 4.90 π mm x mrad. Nevertheless, observe that the aperture of B1 and B2 magnets is flat versus x, the horizontal displacement from the magnet axis, while the aperture of the quadrupoles is a function of x. Thus, if the horizontal closed orbit is distorted, the acceptance of the ring might be a function of x. We carried out calculations with different quadrupole apertures. The results are the following.

Vertical quadrupole aperture	x	Acceptance
± 1.70"	0	4.90 π mm mrad, at the 6 places Eq. (2)
± 1.00"	± 1.40"	4.90 π mm mrad, at the same 6 places Eq. (2)
± 0.80"	± 1.75"	4.14 π mm mrad, at the upstream end of the 6 homologous 7-foot quadrupoles at location 12-1

In conclusion, the change of the acceptance versus the horizontal closed orbit distortion is rather weak.

2. Vertical misalignment of the magnets; no vertical closed orbit distortion.

Introducing in our calculations the actual vertical misalignment of the magnets, we found only a little variation of the aperture of the ring. The following is the list of the locations where the available aperture is less than 4.85 π mm x mrad.

Location	End	Acceptance
A48-5	downstream	4.56 π mm - mrad
(*) D22-3	downstream	4.58 π mm - mrad
C48-5	downstream	4.58 π mm - mrad
D48-5	downstream	4.71 π mm - mrad
F48-5	donwstream	4.72 π mm - mrad
E48-5	downstream	4.75 π mm - mrad
B48-5	downstream	4.76 π mm - mrad
(*) C19-3	downstream	4.85 π mm - mrad

This acceptance has been calculated in absence of horizontal closed orbit distortion (x = 0, everywhere). Observe that, with the exception of the two locations marked with an asterisk, all these locations are the same as those listed in Eq. (2).

There was no variation of the acceptance when we took the quadrupole aperture down to the ± 1.0" (horizontal closed orbit distortion of ± 1.40"). But if the horizontal closed orbit deviation is ± 1.75" in all the quadrupoles where now the available aperture is ± 0.80", the available acceptance decreases slightly more. The acceptance limitation now occurs at the upstream end of the 6 homologous 7-foot quadrupoles at locations 12-1, where the acceptance is 4.14 π mm x mrad. If we compare this with the results in the same identical conditions worked out for the <u>ideal case</u>, we conclude that for large horizontal closed orbit deviation, there is no dependence of the vertical acceptance of the ring on the vertical misalignment of the magnets.

In conclusion, we can say that the actual setting of all the magnets in the main ring is fairly good since it allows a <u>physical</u> acceptance of at least 4.0 π mm x mrad, which should be adequate for a beam of an emittance of 1.5 π mm x mrad at 8 GeV.

Henceforth, our recommendation is not to move magnets up and down any more, and to make periodic survey (say twice a year) to insure the magnets are still located at the same position.

3. <u>Vertical misalignment of the magnets and vertical closed orbit distortion</u>.

We make the hypothesis that it is possible to make an ideal momentum independent vertical steering of the beam to keep the vertical closed orbit deviation as small as possible. We assume also that the vertical center of the field in the quadrupoles lies on the horizontal plane, so that the only possible cause of the closed orbit distortion is the actual elevation of the quadrupoles. With these assumptions we can infer that the low energy closed orbit should look similar to the high energy closed orbit which has been calculated on the basis of measurements of the whole beam displacements around the ring. Calculations show that this closed orbit can be very well represented by 37-th order Fourier analyzed curve[2], which is shown in Fig. 6.

Observe that the closed orbit distortion is, generally, considerably larger than the actual displacement of the magnets, so that, now, serious acceptance limiation is expected.

We carried out calculations in the same way as before. These are the results.

(a) No horizontal closed orbit deviation (x = 0).

The following is the list of the locations with an acceptance value less than 3.5 π mm x mrad.

Location	End	Acceptance
C48-5	downstream	2.74 π mm x mrad
C45-4	upstream	3.14 π mm x mrad
E18-2	upstream	3.16 π mm x mrad
F11-5	downstream	3.26 π mm x mrad
C44-3	downstream	3.28 π mm x mrad
E18-4	upstream	3.40 π mm x mrad
F46-3	downstream	3.41 π mm x mrad
C44-5	downstream	3.44 π mm x mrad
E17-5	downstream	3.47 π mm x mrad

(b) Vertical aperture in the quadrupoles of ± 1.0", equivalent ot a local closed orbit deviation of ±1.40".

No change in the result of the calculation. The above list of locations with the smallest acceptance still applies.

(c) Vertical aperture in the quadrupoles of ± 0.80", equivalent to a local closed orbit deviation of ± 1.75".

The following is the list of the locations with an acceptance less than 3.0 π mm x mrad.

Location	End	Acceptance
F12-1	upstream	2.10 π mm x mrad
F12-1	downstream	2.16 π mm x mrad
E18-1	downstream	2.24 π mm x mrad
E18-1	upstream	2.24 π mm x mrad
C45-1	downstream	2.33 π mm x mrad
C45-1	upstream	2.35 π mm x mrad
B45-1	upstream	2.56 π mm x mrad
B45-1	downstream	2.58 π mm x mrad
F47-1	upstream	2.58 π mm x mrad
F47-1	downstream	2.59 π mm x mrad
A14-1	downstream	2.72 π mm x mrad
A14-1	upstream	2.73 π mm x mrad
C48-5	downstream	2.74 π mm x mrad
F35-1	downstream	2.78 π mm x mrad
F35-1	upstream	2.78 π mm x mrad
B43-1	downstream	2.82 π mm x mrad
B43-1	upstream	2.84 π mm x mrad
E14-1	upstream	2.92 π mm x mrad
E14-1	downstream	2.92 π mm x mrad
D27-1	upstream	2.94 π mm x mrad
A29-1	downstream	2.95 π mm x mrad
D27-1	downstream	2.95 π mm x mrad
A29-1	upstream	2.95 π mm x mrad
C37-1	downstream	2.97 π mm x mrad
C37-1	upstream	2.98 π mm x mrad

In conclusion, we can say that we should avoid keeping the beam too far away from the quadrupole axis (on the horizontal plane). We have experimental indications that the beam pattern seldom exceeds an off-axis deviation of more than ± 1", which according to our analysis is good enough. Also, we should try a local bump to correct the closed orbit at C48-5, getting in this way, at least, a vertical acceptance of 3.14 π mm x mrad which sould be enough if, at the same time, the 8-GeV transport line is properly tuned to match the injection of the beam in the main ring. All this could eliminate the fast beam loss observed after the injection.

References

[1]E. Bleser, H. E. Fisk, R. Flora, private communication.

[2]J. MacLachlan, private communication.

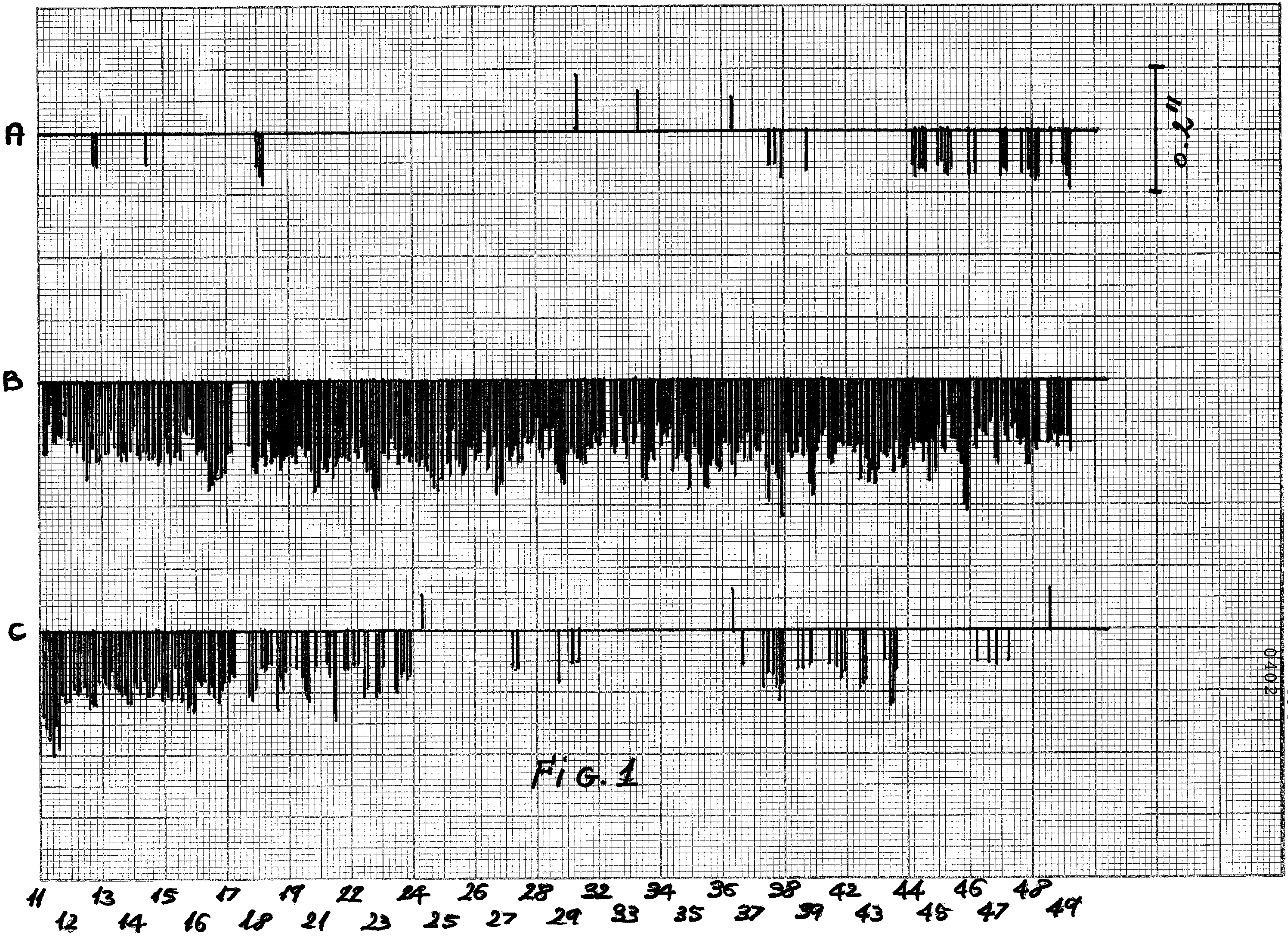
A
B
C
11 13 15 17 19 22 24 26 28 32 34 36 38 42 44 46 48
12 14 16 18 21 23 25 27 29 33 35 37 39 43 45 47 49

FIG. 1

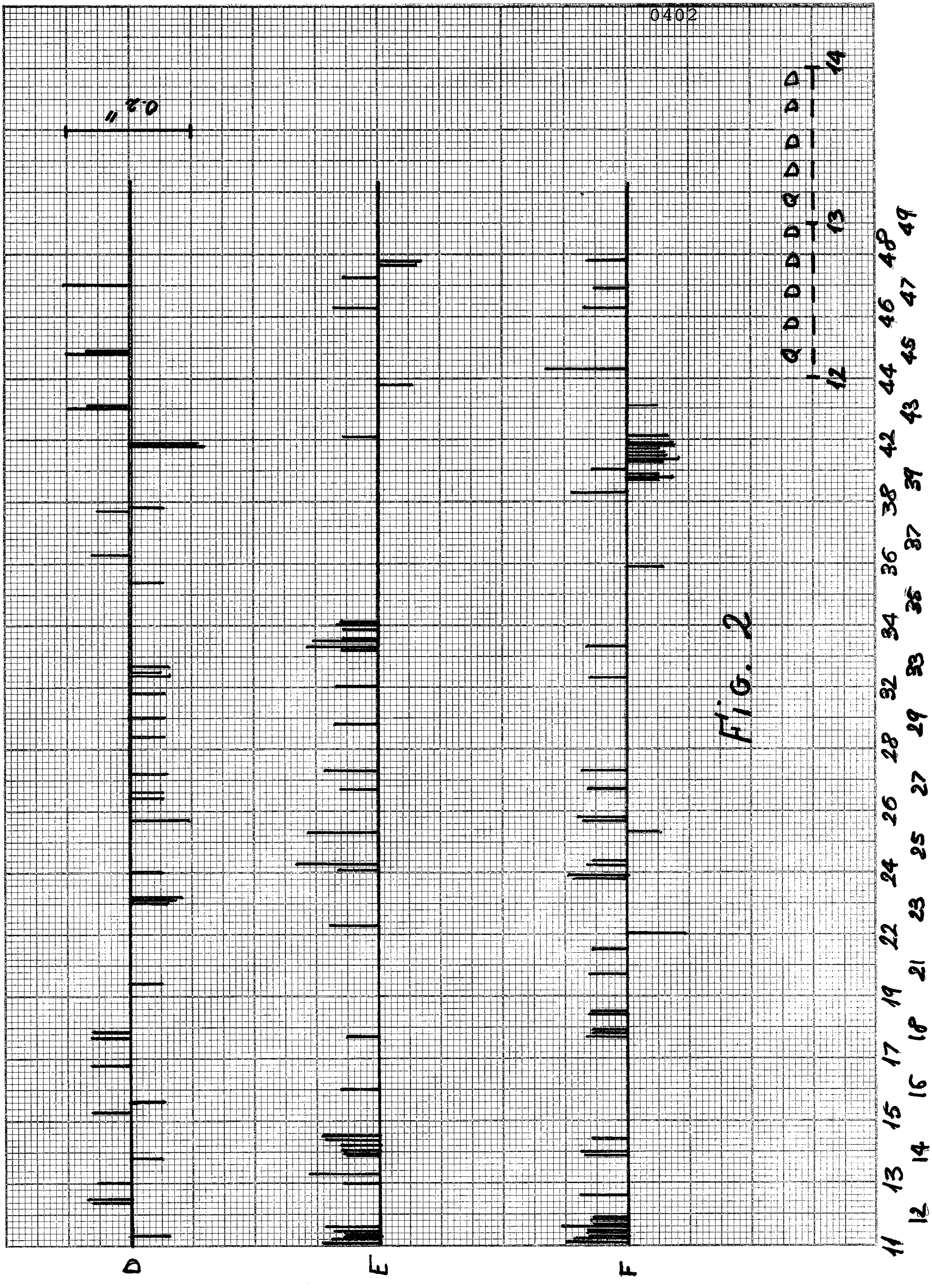
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FIG. 2

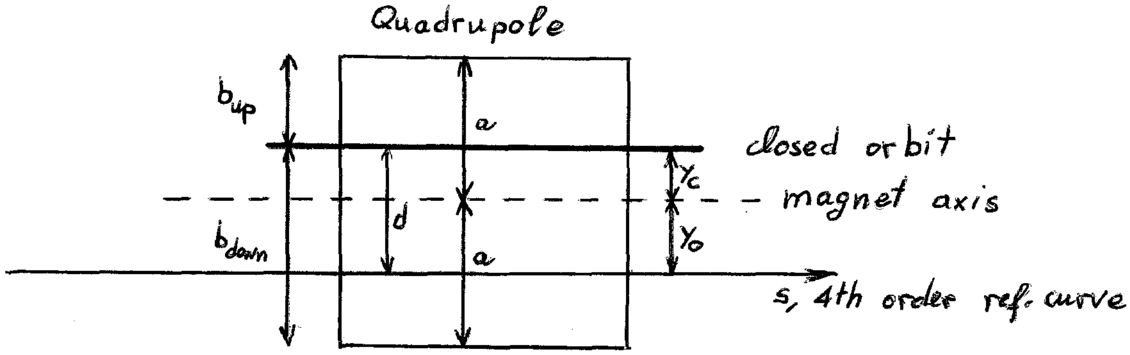


Fig. 3

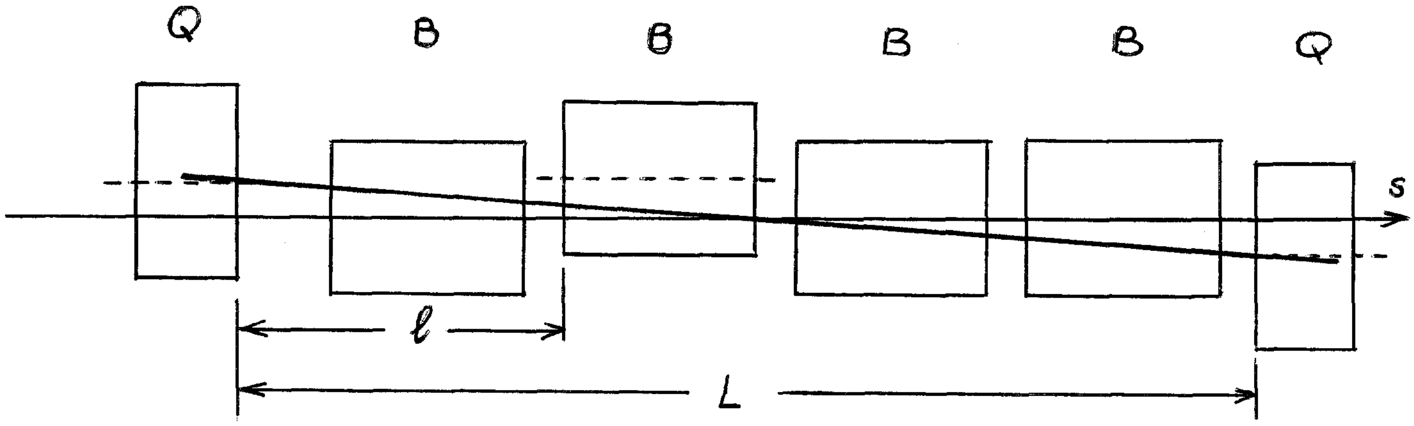


Fig. 4

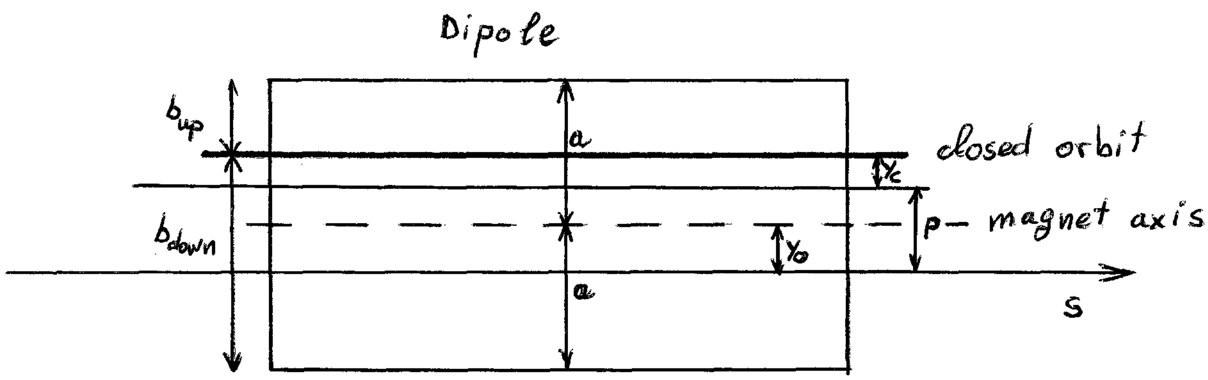
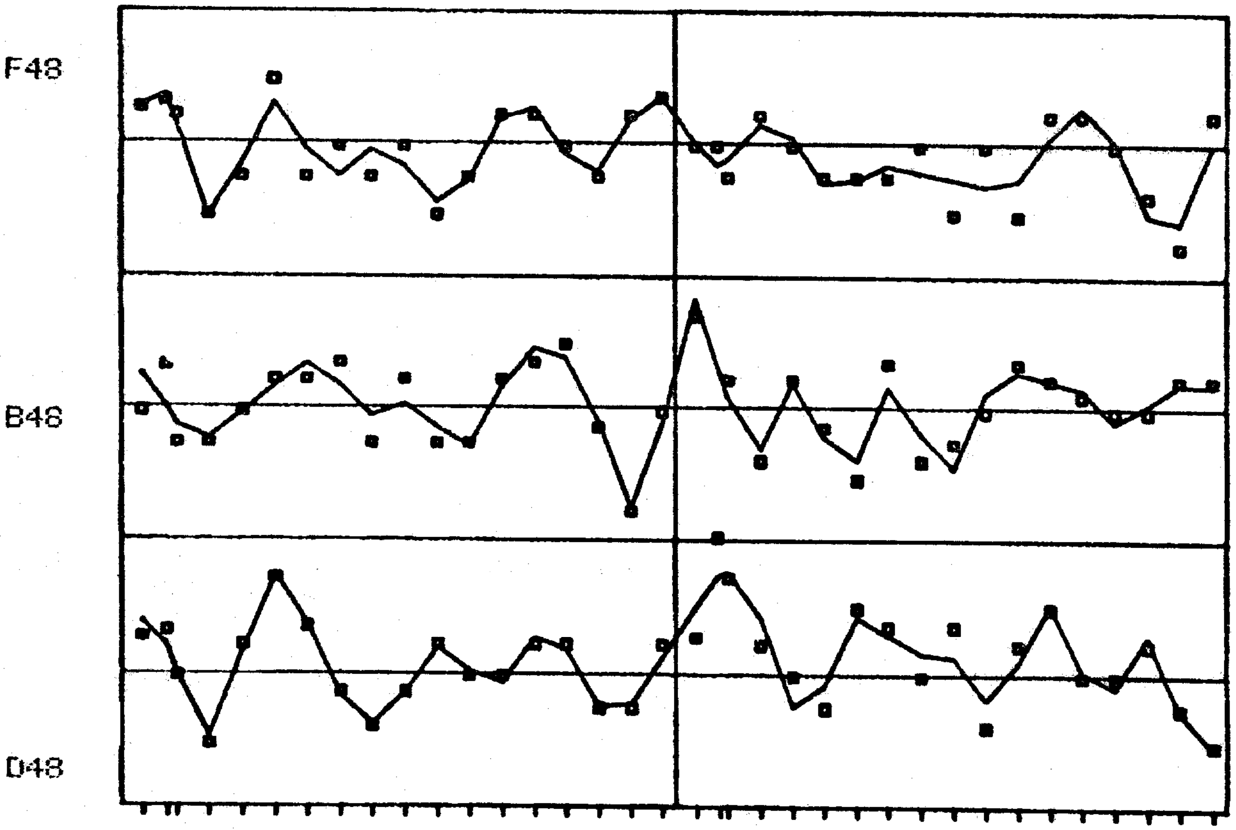


Fig. 5

FIGURE 6



This plot shows $\beta^{-\frac{1}{2}} y_c$ in the 6 sectors of the main ring:

β, vertical beta-value (in meters)

y_c, vertical closed orbit (in inches) from the rectified curve going through the axis of the quadrupoles.

The full scale is ± 0.03 (inches/$\sqrt{\text{meters}}$).

The squares are the measurements at 200 GeV.

The continuous line is the 37-th order Fourier analyzed curve which best fit the measurements.